GET-626C
Supersedes GET-626B

PROTECTION OF POWER TRANSFORMERS CONNECTED TO OVERHEAD CIRCUITS

THE ASA impulse-test code for transformers, C-57.2, enables operating companies to purchase power transformers whose impulse strength is subject to demonstration by test with a 1.5 x 40 microsecond wave of specified amplitude. This affords operators a starting point for providing proper protective measures in service.

The General Electric Company believes that good operating engineering necessitates protective measures to keep service stresses at a reasonable margin below the strength of the transformer, as demonstrated by the factory impulse test. It is the purpose of the following discussion to review the problem of protection and to discuss briefly the factors that should be considered by operating companies in deciding the protection they should provide.

This discussion represents a summary of the opinions of General Electric engineers on the protection of power transformers connected to overhead circuits, but does not imply responsibility for operating practices. The opinions outlined herein are in general agreement with the report of the AIEE Electrical Machinery Committee on "Protection of Power Transformers against Lightning Surges," published in *AIEE Transactions* (1941), Vol. 60, p. 568.

SOURCE OF OVERVOLTAGES

The overvoltages to which transformers are subjected are usually caused by:

(a) Lightning.
(b) System disturbances—switching surges, arcing grounds.

Lightning

The problem of protection of transformers against damage by lightning may be simplified if the lightning overvoltages are divided into three general classes:

1. Direct strokes at the station.
2. Extremely steep wave fronts from strokes on circuits closely adjacent to the station.
3. Traveling waves of the same order of steepness and length as the test wave.

Direct strokes terminating on the conductors within the station structure will, in general, impose a rapidly rising voltage, which will have a magnitude limited by the flashover of the line insulation at the point where the stroke occurs. Direct strokes on station structures will cause a flashover of insulation in case the impedance drop to ground is sufficiently high. Traveling waves reaching the station from strokes at more remote points on the line will impose less rapidly rising voltages but may have magnitudes which will flash over station insulation.

Sufficient data are not available to determine accurately all of the characteristics to be expected of direct strokes. However, limiting values will be given, although these values may be modified somewhat by field data yet to be obtained:

(a) The maximum voltage which can appear on an unprotected transmission-line conductor struck by lightning will depend on the amount of current in the stroke and on the impedance to ground of the discharge path, and in extreme cases will be great enough to flash over or puncture any insulation which it is economical to provide.

(b) The current in the stroke may be as high as 220,000 amperes.

(c) The rate of voltage rise at the point struck will depend upon the rate of current rise in the stroke and the impedance to ground. The rate of current rise may be as high as 40,000 amperes per microsecond.

(d) Duration of the stroke current to half crest value is of the order of 15 to 120 microseconds.

System Disturbances

Switching Surges

Switching surges may range in magnitude up to 5½ times normal line-to-ground operating voltage. These switching surges are usually of relatively long duration, so that the 60-cycle flashover characteristics of insulation must be considered in dealing with them. There is, however, some evidence to indicate that for switching surges in excess of about four times normal, the surge flashover or breakdown kv is somewhat higher than the 60-cycle crest flashover or breakdown kv.

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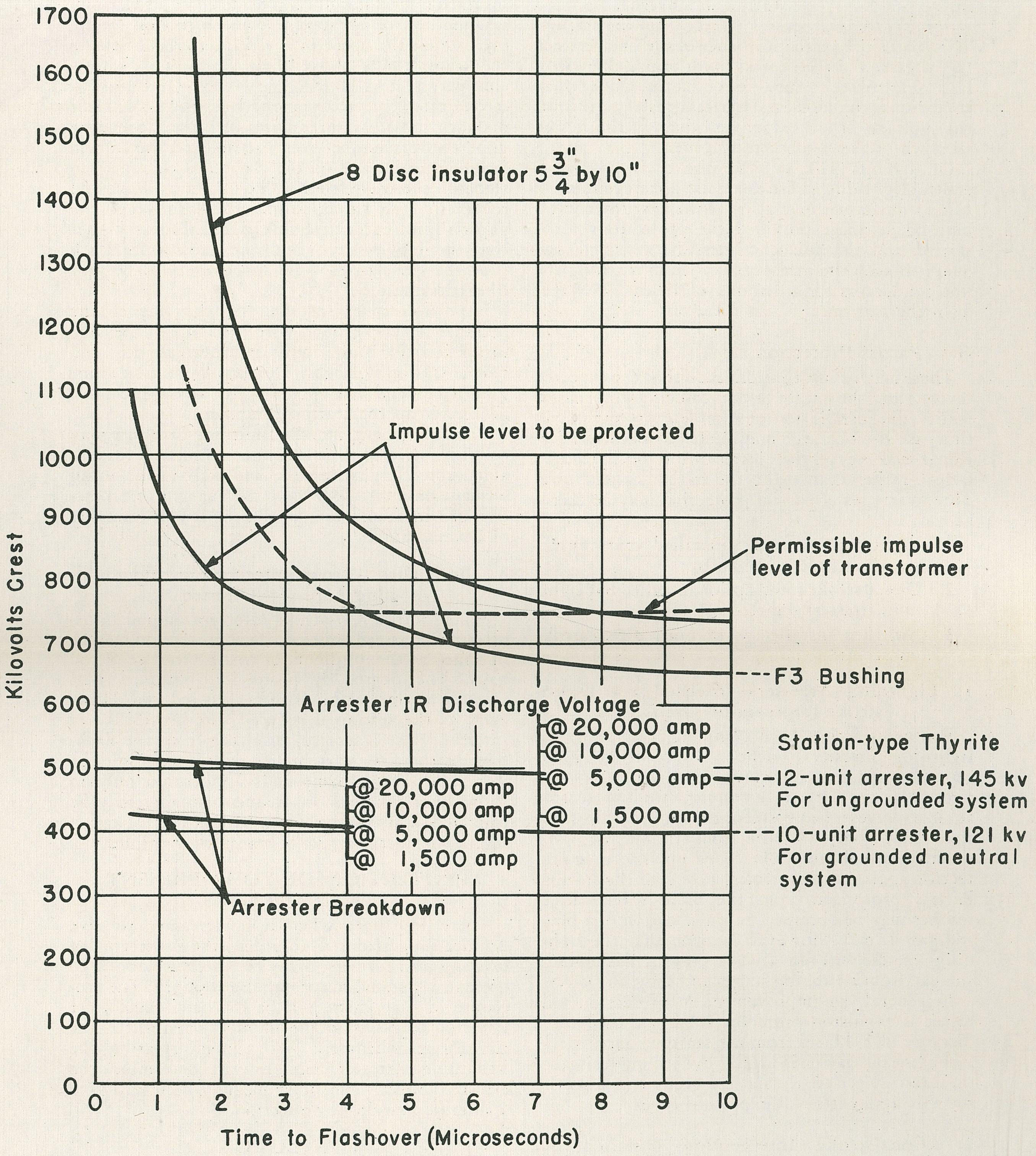

Fig. 1

Volt-time characteristics, 1½-40 positive wave, 138-kv system (tentative data)

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Arcing Grounds

Arcing ground overvoltages are, in general, of the same order of magnitude as switching surges but they may be of prolonged duration, and the likelihood of occurrence is relatively much less. Dangerous arcing ground overvoltages occur on isolated neutral systems or on systems grounded through a high impedance other than a ground-fault neutralizer.

PROTECTIVE MEANS

On the basis of the overvoltages which might be expected, it is clear that it is necessary to protect power transformers from direct strokes of lightning, traveling waves, and switching and arcing ground surges. There are, in general, five methods of protection against overvoltages, some of which can be used separately, or in combination, depending upon the degree of protection desired by the operator. These are:

1. Interception of direct strokes.
2. Lightning arresters.
3. Expulsion protector tubes.
4. Plain air gaps.
5. Station capacitance.

Interception of Direct Strokes

For effective interception of direct strokes, the means provided must be such that the stroke will terminate upon it and not upon the lines or apparatus, and the discharge path from it to ground must be of such low impedance that the discharge current will not build up sufficient voltage to cause flashover to the circuit being protected.

This direct-stroke interception at the station may take the form of overhead ground wires or an extension of the steel structure above the conductors to a sufficient height to intercept the stroke. This height is usually determined from a protective cone whose base radius is not greater than its height. Direct-stroke interception of the lines adjacent to the station is best provided by means of overhead ground wires. The proper distance from the station to which the overhead ground wires should be extended, and the clearance between the conductors and the ground wires can be estimated for any given case. See *GEU-14A* and *GEA-2008*.

When the station and the adjacent lines have direct-stroke interception, as outlined in the preceding paragraphs, all lightning impulses will enter the station through the surge impedance of the line, and the resultant maximum voltage in the station can be estimated.

Lightning Arresters

The magnitude of a traveling wave entering a station is determined by the surge impedance and the flashover voltage of the line. The best means of providing protection against traveling waves is by the use of the station-type Thyrite* lightning arrester. Modern Thyrite lightning arresters are available with established impulse volt-ampere characteristics which can be demonstrated by commercial impulse tests. This gives the operator a definite basis for estimating the service stresses to which his transformers may be subjected under all conditions of traveling waves. A lightning arrester will successfully discharge some direct strokes, but should not be depended upon for complete protection for all direct strokes, or to withstand continuous discharging from prolonged arcing grounds.

Expulsion Protector Tubes

Expulsion protector tubes may be used to establish, on grounded-neutral systems, a reduced line flashover level near the station without attendant line outages. When used in conjunction with lightning arresters and overhead ground wires, they will reduce the magnitude of the wave reaching the station and thus augment the effectiveness of the protective scheme. The impulse discharge level of the expulsion tube is too high for it alone to afford suitable protection to station equipment.

Plain Air Gaps

A comparison of volt-time curves shows that the impulse flashover of air gaps increases much faster than the impulse breakdown of transformer insulation, as the time to flash over or break down becomes less, so that extremely low gap settings would be needed to protect apparatus against waves which would reach gap flashover value in less than 2 or 3 microseconds.

If the gap is set low enough to give a practical margin of safety for such steep waves, its flashover voltage for long waves may be so low that there is a possibility of flashover on switching surges and a probability of flashover on long-wave impulse surges of low amplitude, resulting in unnecessary system outages. Moreover, the flashover of a plain gap at the terminals of a transformer produces a practically instantaneous voltage drop or steep wave tail, causing higher voltage stresses within windings than would occur if the same crest voltage were removed more gradually, as by discharge through an arrester. Flashover of air gaps will usually cause a system outage, and therefore cannot be considered as providing practical protection.

Station Capacitance

For the station capacitance to be effective, the traveling wave must enter the station through the surge impedance of the line. The inherent line-to-ground capacitance of station apparatus and buses acts to slope the front of an incoming wave, and, if the wave is of short duration, may have an appreciable effect on lowering its amplitude.

PROTECTIVE SETUPS

(A) Complete Protection (Fig. 1)

Based on present-day knowledge, the best protective setup consists of Thyrite lightning arresters, supplemented by proper direct-stroke interception over the station, and overhead ground wires extending at least 2500 feet from the station. This places the surge impedance of the line between the arrester and the nearest point of possible direct lightning stroke to the line conductor. Under these conditions, the modern Thyrite arrester will limit the voltage to a value well below the tested strength of the modern transformer.

On circuits 110 kv and above, if grounded-neutral lightning arresters are used, the economy of using transformer insulation of the next lower class may be justified, provided the protection of the station and the adjacent lines is considered adequate to keep the direct strokes from reaching the line conductors for a distance of at least 2500 feet from the station.

(B) Partial Protection

There may be installations such that the expected revenue and the nature of the load do not appear to justify the installation of complete protection. In this case the operator may prefer to take an additional risk of service interruption or apparatus failure rather than make the higher expenditure. Three varieties of partial protection may be classified as:

1. Lightning arresters installed but direct-stroke interception omitted.
2. Direct-stroke interception installed but lightning arresters omitted.
3. Air gaps installed with both direct-stroke interception and lightning arresters omitted.

1. Lightning Arresters Installed but Direct-stroke Interception Omitted

For years it has been common practice to use lightning arresters without direct-stroke interception to protect apparatus on 15- to 110-kv systems. Modern Thyrite arresters afford protection against waves of any steepness, originating more than about one-half mile from the station. This practice cannot always be relied upon to give protection against direct strokes at or near the station. Partial protection from the more severe direct strokes may be obtained by the addition of a plain rod gap. It may, however, happen that the lightning arrester will not always prevent flashover of the gap from switching surges and traveling waves.

In general, an improvement in protection will result if expulsion protector tubes are used for a distance of 2500 feet from the station, particularly if the line insulation is high. Low ground resistance or interconnection to station ground is essential for this application of expulsion tubes.

2. Direct-stroke Interception Installed but Lightning Arresters Omitted

When direct-stroke interception is installed, but lightning arresters are omitted, the station equipment may be stressed up to the flashover of the station insulation, unless some other means are taken to reduce the voltage. In such a case, the use of a plain rod gap set sufficiently below the basic insulation level might be considered as an economical method of obtaining some protection. However, unless the operator is willing to risk stressing the transformers above their strength by short-time waves, it will be necessary to extend the direct-stroke interception along the lines for a sufficient distance (possibly three miles or more, depending upon the relation between the line and the station flashover levels and on the station capacitance) to slope off the wave front of the incoming wave and reduce its crest value, so that the flashover of the gap will not occur at a voltage equal to or higher than the impulse strength of the transformer. Each time the gap flashes over, an outage will be very likely to result.

Expulsion tubes installed on the line at the entrance of the ground-wire section, if the line insulation is high, will improve service and reduce station voltages. The expulsion tube alone cannot be depended upon to offer any appreciable protection to the station equipment.

Therefore, omitting the lightning arresters may result in little or no saving in investment if reasonable protection is desired, and will result in an element of uncertainty as to the margin of protection obtained, and also in an increase in the number of system outages.

3. Both Direct-stroke Interception and Lightning Arresters Omitted

When both direct-stroke interception and lightning arresters are omitted, some protection may be obtained at the minimum of cost by the use of rod gaps. The degree of protection obtained will increase as the setting of the gap is reduced. However, as the setting is reduced, the possibility of interruptions to service, resulting from the flashover of the gap, particularly when wet, will be increased. This scheme finds application only in those cases where more frequent outages may be tolerated, and where the operator is willing to accept a considerable risk of transformer failure.

PROTECTION OF YOUR PRESENT TRANSFORMERS

There are times when it is necessary to give definite suggestions in regard to the protection of existing transformers, many of which are not up to present-day standards of impulse strength. The procedure in such cases will be for our Transformer Division to estimate the impulse strength of the transformer when new. With this information, the Lightning Arrester Section will determine the arrester and supplementary means which will give a suitable margin of protection.

CONCLUSION

The ASA impulse-test code, C-57.2, enables operating companies to obtain power transformers having a demonstrated impulse strength. As outlined above, suitable means are available and should be utilized to keep service stresses at a reasonable margin below the demonstrated transformer strength.

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* Reg. U.S. Pat. Off.